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Geo-Archeological Interpretation of Acheulian Calc-Pan Sites at Doornlaagte and Rooidam (Kimberley, South Africa)

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Two Acheulian occupation sites of the Kimberley District, Doornlaagte and Rooidam, are found geologically sealed and in semi-primary context within complex sequences of calcareous and arenaceous sediments. The sedimentary columns are analyzed and interpreted in terms of sedimentology and stratigraphy, indicating major occupation along the margins of shallow, seasonal lakes; sporadic visits to the fluctuating shoreline are also indicated thereafter, until the Doornlaagte playa began to dry out, and at Rooidam until the whole depression was submerged. The evolution of the related calcareous pans is discussed and attributed to cycles of alternating erosion (aeolian, chemical and fluvial) and deposition (lacustrine and colluvial, including reworked aeolian components). In addition to pedogenetic "calcretes," most of the limestones of the pan sedimentary sequences are lacustrine in origin. Palaeosols also include fersiallitic soils. The various geomorphologic events indicate repeated and appreciable environmental changes during the mid-Pleistocene. The detailed climatic oscillations recorded at Doornlaagte and Rooidam cannot be correlated, and the latter site is appreciably younger, with a provisional Th/U date of 115,000 BP for the late Acheulian ("Fauresmith") occupation.

Introduction

Hand-axes of Acheulian type were first discovered in the northern Cape Province during the course of diamond workings of the late 19th century. Destined to become best known in the international literature were the Acheulian occurrences of the Vaal gravels (see Cole, 1961, pp. 28–159, for a comprehensive analysis of the existing collections). However, hand-axes were also recovered in the Kimberley diggings, and the McGregor Memorial Museum at Kimberley has more recent records of such artifacts from nearby Kamfersdam and Klipjies Pan, as well as from the road to Barkly West and the Modder-Riet river confluence (Fock, 1965, 1972; also Clark, 1967, p. 48). The contextual significance of these incidental finds around Kimberley could not be envisaged prior to the scientific excavation of two newly-discovered sites at Doornlaagte, by Mason in 1963, and at Rooidam, by Fock in 1964.

Doornlaagte and Rooidam provided a new perspective on Acheulian ("Earlier Stone Age"—"Fauresmith") settlement in the Northern Cape. Previous associations had been with the abandoned channels of the Vaal River and their cover deposits (see Butzer *et al.*, 1973). Now it was clear that Acheulian occupancy had also extended to the closed depressions or pans of the broken, upland plains between the Vaal and Riet Rivers.

Excavation in calcareous pan sediments was pioneered by Mason at the Middle Stone Age site of Kalkbank, north-central Transvaal, beginning in 1954 (Mason, 1962, p. 63 ff, with geological data by A. B. A. Brink and palaeontology by H. B. S. Cooke; also Mason, 1967, pp. 6–7, Figures 5–6; Netterberg, 1969*a*). The exigencies of such difficult excavations, requiring the removal of many tons of thoroughly cemented material by mining equipment, has limited such study to Kalkbank, Doornlaagte and Rooidam, even though Middle Stone Age artifacts are known to occur within other such sedimentary sequences elsewhere in southern Africa (Kent & Rogers, 1947; G. J. Fock, 1972).

The writer's attention was first directed to Doornlaagte and Rooidam in 1969 during the first season of geological study at a variety of Pleistocene archaeological sites in South Africa. They were without parallel as Acheulian pan sites, and no sedimentary sequence of pan deposits anywhere had yet been studied in detail and interpreted. The profiles at both localities were sufficiently provocative for analysis of a suite of samples collected in 1969 and again in 1970, and the results provide stratigraphic sequences as well as palaeo-environmental data for the poorly understood mid-Pleistocene time range between the australopithecine cave breccias on the one hand (Butzer, 1971*b*, 1973*b*) and late Pleistocene to Holocene alluvial sequences on the other (Butzer, 1971*a*).

Geomorphologic Terminology

Pans are broad, shallow depressions with internal drainage, serving as evaporation surfaces for run off and precipitation. The Afrikaans term is partly equivalent to the Mexican-American usage of *playa* and the French-Saharan *sebkha*—with a significant difference that the majority of pans are erosional in origin. Such endorheic depressions everywhere vary considerably in size, relief, complexity and geochemistry, while their regional distribution and frequency are equally variable. Functional pans in South Africa are floored by combinations of very fine detritus and chemical precipitates, mainly inorganic but occasionally including diatoms, mollusca and, possibly, algal secretions. In the Kimberley District saline evaporites are relatively uncommon and appear to be restricted to Dwyka tillites and shales, in the vicinity of mineral springs charged with sodium salts. Far more characteristic is a range of deposits covering the spectrum from calcareous clays to clayey marls or chalks, although sandy or gypsiferous interbeds are present in many instances. The drainage basins of such pans commonly include several generations of indurated, older deposits of analogous types. In part these can be related to specific shorelines, as in the case of the Alexandersfontein Pan, near Kimberley (Figure 1) (Butzer *et al.*, 1973). More commonly, however, poorly exposed sheets of calcareous hardpans appear to mantle broad surfaces of the upland between the Vaal and Riet Rivers. In fact, such limestones of presumed pan origin form the most typical surface deposits of the region.

Groups of coalescent pans may form wide basins or meandering swales locally known in Afrikaans as *vloers* (Wellington, 1955, p. 26; King, 1963, p. 228) and characterized by takyr soils (Van Der Merwe, 1963, p. 326 ff.; Wellington, 1955, pp. 75 ff., 323) or more commonly in the Kimberley area by marly deposits low in gypsum and sodium salts. Importantly, Wellington (1955, pp. 314, 331) distinguishes *vloers* from the loosely-employed concept *vlei*. The latter refers to a wide range of marshy ground with water-logged soils, whose texture and composition are closely related to those of adjacent zonal soils. As a geomorphic and sedimentary appelate, *vlei* is best restricted to the flat surfaces and swales of sluggish drainage in the wetter sections of the High Veld. Here the pedo-sediments consist of dark, cracking, montmorillonitic clays, possibly a meter or more in depth and classified as vertisols (see Dudal, 1965, pp. 100, 107 ff.).

Modern Soils, Vegetation and Climate

The zonal soils of the Kimberley region consist primarily of thin, brownish, loamy materials with modest carbonate enrichment. Both natural and accelerated erosion have extensively stripped the solum off inclined surfaces subject to sheetwash, and most profiles show evidence of reworking by colluvial agencies. Reddish sandy soils, whether deep or shallow, are also common but restricted to areas with veneers or substantial accumulations of aeolian materials (Van Rooyen, 1971). The vegetation cover is a severely overgrazed thorn savanna (the *thornveld* of Acocks, 1953), with scrub parkland or copses on shale and lava bedrock, and tall, widely-spaced camelthorn acacias (*A. giraffae*) locally preserved on sandy soils. Mature trees are almost absent from the

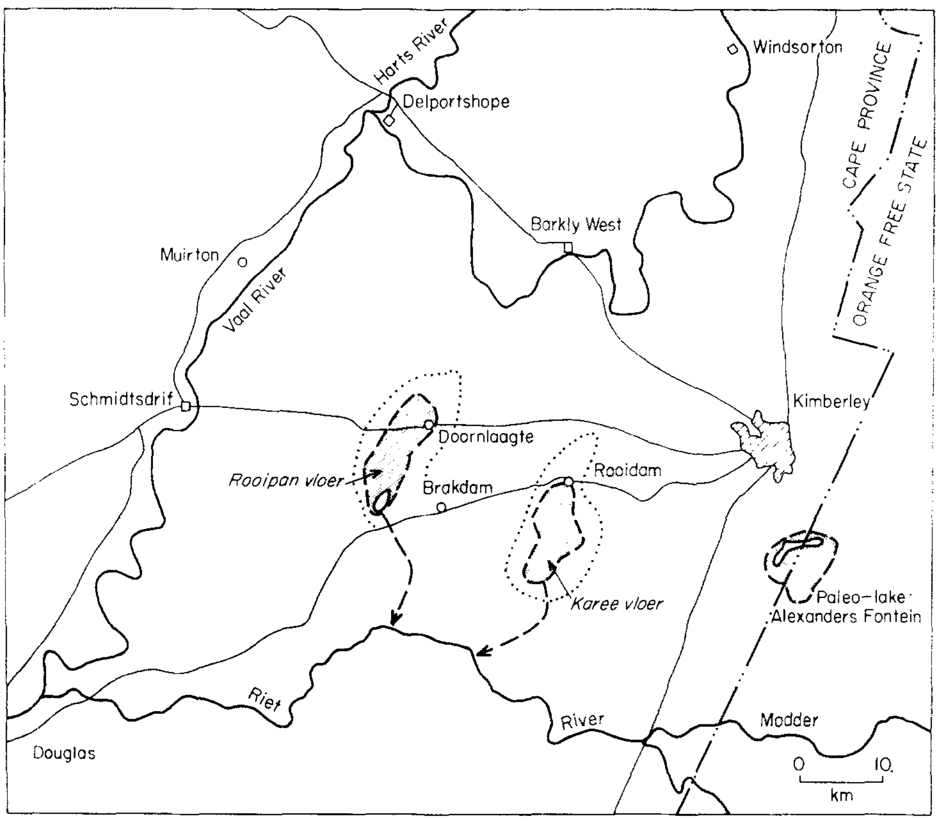

Figure 1. The Kimberley Region and palaeo-drainage features at Doornlaagte and Rooidam.

vicinity of the Cape Town–Johannesburg rail track as a result of substantial wood-cutting activity to provide mine-shaft supports and fuel in the early days of the diggings (Fock, 1972).

The climate is *BSkw* by the Koeppen classification and dry-semiarid by the Thornthwaite system (DB_3d), with rainfall decreasing in a westerly direction from about 400 mm at the Orange Free State border, near Kimberley, to 300 mm in the Vaal lowlands at Schmidtsdrif (see Figure 1). Precipitation is strongly concentrated in the summer half-year, with 80% coming in the months November through April (see *Climate of South Africa*, 1965), and characterized by high-intensity, short-duration falls leading to rapid surface run off. The greatest frequency of strong winds capable of sand transport is from a northerly direction at all seasons, but their incidence is greatest during the dry, winter half-year (see *Climate of South Africa*, 1960). However, the distribution of Pleistocene aeolian sands (see Van Rooyen, 1971, map) exhibits northwest to southeast trends, suggesting either that effective winds have been different in the past, or that sand transport represents a vector modified by southwesterly cross-winds, such as are now prominent during the rainy season.

Laboratory Techniques

The sedimentary analyses (Figures 2 and 4) were carried out in the Paleo-Ecology Laboratory of the University of Chicago's Anthropology Department. Techniques are outlined briefly since the samples posed a number of technical problems, with the methods ultimately employed selected to derive a maximum of informative data.

(1) Decalcification in 20% hydrochloric acid, so providing calcium carbonate content for bulk samples as well as residues suitable for further study. Heat did not measurably assist in the breakdown of less soluble samples, from which we conclude that dolomite is not present in measurable proportions.

(2) Hydrometer analyses, using a 5% solution of sodium pyrophosphate as peptizing agent. This technique was used to determine the fractions under 2, 2–6, 6–20 and 20–63 μm in diameter, although the clay-size fraction was subsequently augmented by that component soluble in sodium hydroxide. This approximation was unavoidable since the clays were generally cemented by colloidal silica when oven-dried after acid treatment. In order to estimate the proportion of silica mobilized in acid, precipitation of flocculated colloids was measured in a calibrated cylinder and the ratio of clays and colloids estimated after drying, reweighing and, following hydrometer testing, removal in sodium hydroxide. Although titration and filtration of the colloids after boiling in acid is technically more desirable, it was found that this removed only an arbitrary part of silica that ranges the full spectrum from crystalline to mobile amorphous forms. The total of clays and colloids among the non-carbonate residues is shown in the third column of Figures 2 and 4, whereas they are separated in the second column.

(3) Wet-sieving of the residues remaining after decalcification, hydrometer analysis, and removal of secondary aggregates in sodium hydroxide. Standard mesh sieves (37, 63, 210, 595 μm; 2 and 6·4 mm) were employed and we have deliberately refrained from using logarithmic phi-classes in favor of simpler micron grades. For the purpose of differentiation, fine sands 63–210 μm are distinguished from coarser sands in the third column of Figures 2 and 4.

(4) Textural classes, based on 7 or more grade-sizes, were then determined according to the textural classification of Link (1966). Sorting of whole samples follows Payne (1942), whereby sorting is good when 2 grade-sizes total 90% (or more), moderate when 3 or 4 grade-sizes total 90%, and poor if 5 or more total 90%.

(5) In order to isolate the potential aeolian component of samples distinctly bimodal in distribution (maxima under 2 μm and near 110 μm), sorting and skewness of the greater-than-37-μm component were determined separately. The Trask coefficient of sorting is $So = \sqrt{Q_1/Q_3}$, and skewness, $Sk = Q_1 Q_3/(Md)^2$, where Q_1 is the first quartile, Md the median, and Q_3 the third quartile of the cumulative textural curve, with $Q_1 > Q_3$. The indices were found to be adequate for reliable differentiation among the 30 samples analyzed. In particular, sorting is moderately good (*So* values 1·39–1·81) for all samples, while 22 of 30 samples showed a symmetrical grain-size distribution (*Sk* values 0·9–1·1),

2 were positively skewed with a tail of coarser sand (*Sk* 1·1–1·14), and 6 negatively skewed with a tail of silt (*Sk* 0·75–0·9). These data are shown in the last column of Figures 2 and 4.

(6) Sand-sized residues were microscopically scanned (prior to alkali separation) for minerals other than quartz, with semi-quantitative estimates of quartz grain rounding and frosting. The last two qualities are shown by relative curves in the fourth column of Figures 2 and 4. Our limited confidence in the value of traditional quartz micromorphologies (see Butzer & Gladfelter, 1968) did not seem to justify systematic study, although future work with the electron scanning microscope will be desirable.

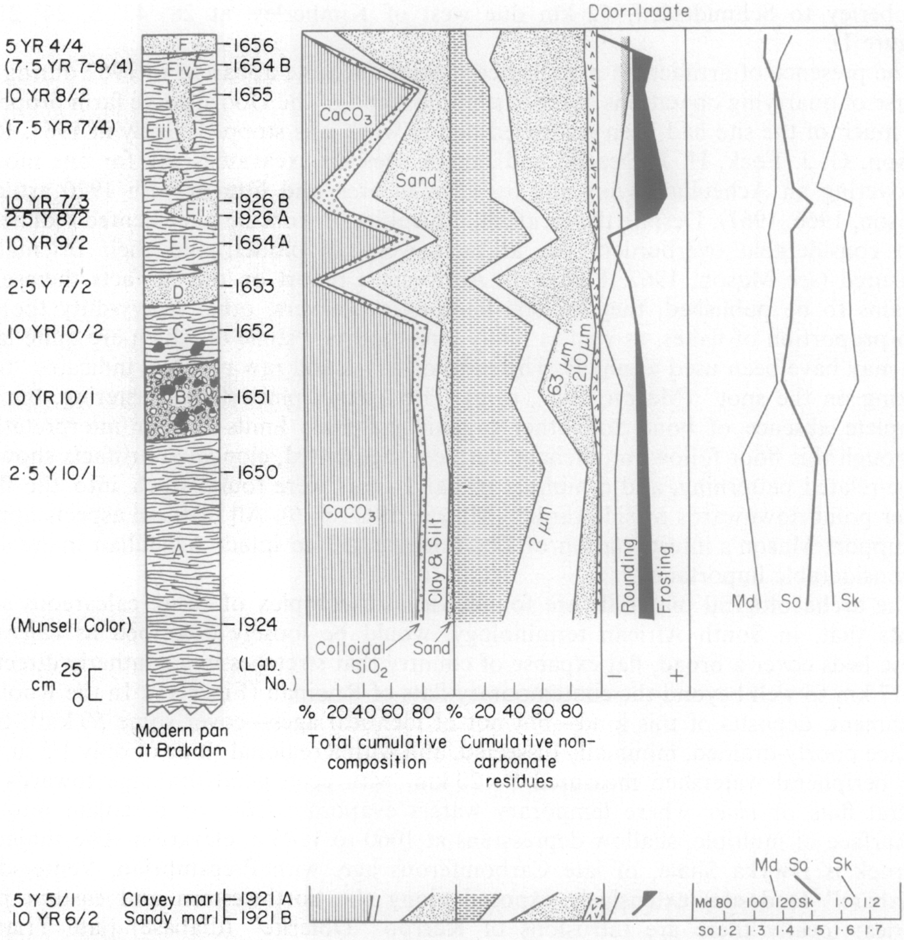

Figure 2. Sedimentary data from Doornlaagte (see text) with comparative analyses of modern pan sediments at Brakdam.

(7) pH values and electrical resistance (mV) were determined for all samples sufficiently friable for the purpose. The former ranged from 6·8 to 8·7, the latter from +80 to +220. The sequential variations were erratic and of insufficient interest to warrant inclusion in Figures 2 and 4.

(8) Finally, Romano Rinaldi and Nathan Hawley of the Geophysics Department of the University of Chicago carried out X-ray analyses of 6 samples, both whole and after

decalcification in highly dilute acetic acid. These confirmed that calcite, quartz and colloidal silica (at least partly in the form of calcium silicate) as well as expandable clays (illite, montmorillonite) were the normal constituents of these sediments. A more exacting geochemical study would obviously yield more specific information on the chemical processes accompanying former subaqueous sedimentation.

Doornlaagte

The nature of the site

The Acheulian site of Doornlaagte is situated just north of the highway from Kimberley to Schmidtsdrif, 42 km due west of Kimberley, at 28° 43′ S, 24° 21′ E (Figure 1).

The presence of artifacts in a geological context became apparent in 1962 during the course of quarrying operations at the easternmost end of the Doornlaagte farm property, but much of the site had been destroyed before work was stopped. Early in 1963, R. J. Mason, G. J. Fock, H. J. Deacon and Janette Deacon excavated here for one month, uncovering an Acheulian living site 6 × 15 m in area and littered with 1920 artifacts (Mason, 1966, 1967). Despite the technical difficulties of working in cemented sediments, with considerable overburden, the artifacts were all plotted and their orientation measured (see Mason, 1967, Figure 3). Although a report on the artifacts themselves remains to be published, they include hand-axes, cleavers, other heavy-duty tools, a high proportion of flakes, as well as many "manuports," some of which are quite large and may have been used as anvils. The ratio of flakes and raw material indicates "tool-making on the spot" (Mason, 1967, p. 6). The artifact plots show clustering, but the complete absence of bone and other organic materials limits further interpretation. Although this floor follows an inclined surface, the plotted, elongated artifacts show no slope-related patterning, and a number of hand-axes "were found stuck into the floor either point downwards or sidewards" (Mason, 1967, p. 6). All of these aspects appear to support Mason's interpretation of Doornlaagte as "an intact Acheulian living site" of considerable importance.

The archaeological materials are found within a complex of white calcareous sediments that, in South African terminology, would be loosely described as *calcretes*. These beds cover a broad, flat expanse of country that stretches in a southerly direction for 17 km to well beyond the contemporary flats of Rooipan (Figure 1). In the Rooipan catchment, deposits of this kind—but not of identical ages—cover some 50 km^2, their surface poorly-drained, minimally dissected, and with a regional slope of only 1·5 m/km. The peripheral watershed measured 8 × 20 km, with centripetal drainage towards the central flats or *vloer* where temporary waters evaporate from or percolate into the subsurface of multiple, shallow depressions at 1060 to 1105 m elevation. The subjacent bedrock is Dwyka Shale, of late Carboniferous age, with Precambrian, Ventersdorp "Diabase" (andesite) extensively exposed along the northwestern and eastern peripheries: locally there are intrusions of Karroo "Dolerite" (diabase) (late Triassic, DuToit, 1954).

The Doornlaagte site lies at the northeastern edge of this *Rooipan Vloer*, at 1100 m. Diabase outcrops to the southwest and northeast at distances of a few hundred meters, while a group of dolerite plugs form buttes and ridges (Afrikaans: *koppies*) with a relief of 50 m, immediately south, at distances of 1·5 km and more. An almost featureless surface extends to the west. The general area is covered by the 1:50,000 topographic map sheets 2824-CB and CD (Gong-Gong and Koedoesbergdrif), compiled in 1969–70. The best geological coverage is the 1:238,000 Cape Province sheet 42 (DuToit, 1907–08), which does not, however, show local surficial deposits.

The sedimentary sequence at Doornlaagte

A schematic section has been published by Mason (1967, Figure 4), after unpublished stratigraphic observations of H. J. Deacon. From bottom to top there are:

(1) Over 2·1 m hard, white calcrete;

(2) 0·6–0·9 m greenish calcrete with packed masses of artifacts both on and below the "floor" at or near the top of this bed (see Mason, 1967, p. 6);

(3) 1·5–1·8 m laminated calcrete with red sand lenses and shells of *Succinea;* scattered artifacts;

(4) 0·3–0·4 m reddish sand.

During the course of brief visits to the site in 1969 (with A. J. B. Humphreys and R. G. Klein) and 1970 (with G. J. Fock and D. M. Helgren) the writer reconstructed a similar but more detailed profile, and collected 11 representative sediment samples. The composite section of Figure 2 is derived from the existing witness section and Mason's 3 test pits. The stratigraphic units are described below in terms of macro-characteristics and laboratory analyses:

Unit A. Over 2·4 m, base unseen. Cemented, well-stratified, in part laminated or wavy-bedded, white, cryptocrystalline calcite. The non-carbonate residue ranges from 20 to 23% of the total bulk, and consists of moderately-sorted, sandy-clay silt or silty clay, with 34–63% clays and colloidal silica under 2 μm. Apart from calcite and quartz, X-ray diffractogram shows the presence of illite and montmorillonite (in approximate proportions of 2:1), together with potash feldspars. (Contact wavy, abrupt, and erosional.)

Unit B. 0·6 m. Cemented, stratified matrix of white cryptocrystalline calcite with a non-carbonate residue (26%) of moderately sorted silty sand-clay, including some 40% colloids and clay. Inclination 1–5°, dipping to south or southwest. This sediment embeds (a) great masses of rolled, coarse-grade calcite pebbles, derived from slabs of Unit A; (b) scattered coarse-to-cobble grade pebbles of Precambrian diabase and Karroo dolerite, either rolled or spheroidally weathered; (c) micro-pockets of unconsolidated, laminated, light gray (10 YR 7/2), silty-clay sand; and (d) cultural materials, including mint, waterworn or rolled artifacts (tools and *débitage*) of diabase and unmodified rock, difficult to distinguish from natural occurrences in the same stratum. The calcite pebbles are definitely not *in situ* concretions; they are lithologically identical to upper Unit A (instead of the matrix) and they are subrounded, with a distinct weathering cortex. A gravel analysis of 50 such pebbles, by the modified Lüttig system (see Butzer, 1971*a*, p. 166 ff.), gave an index of rounding of 24·5% (with 53·8% coefficient of variation), E/L and E/l ratios of 55·8% and 73·2% respectively (where L is length of major axis, l minor axis, and E pebble thickness), with a median length of 3·97 cm. The igneous cobbles, blocks, and artifacts all show a thick, olive (5 Y 5/3) patina or cortex as a result of post-depositional alteration (within the sediment body) affecting primarily the olivine minerals. Similar rubbles of very crude rock have been extensively exposed by the quarrying and they appear to extend beyond the confines of the sedimentary *vloer*, littering the surface, where the patination takes on brown, red or gray hues. We therefore feel that this almost ubiquitous concentration of igneous rock constitutes a "stone line," fortuitously coincident with the archeological horizon.

There are local proliferations of *Succinea* sp. (a hygrophile, terrestrial snail) in this bed, and all the individuals measured were approximately 2 mm in length. (Contact wavy, abrupt and erosional.)

Unit C. 0·5 m. Cemented, stratified and banded, white, cryptocrystalline calcite. Inclination identical to unit B. The non-carbonate residue (24%) is a moderately-sorted silty-sand clay, with some 55% colloids and clays, and including scattered igneous pebbles (commonly up-ended) and artifacts. X-ray analysis showed the presence of illite and montmorillonite (in approximate proportions of 3:2), as well as potash feldspars. Occasional *Succinea* sp. (Contact wavy, abrupt, interdigitated and conformable.)

Unit D. 0·3 m. Extensive lens of partially-cemented, weakly stratified, light gray, moderately-sorted, silty sand with igneous granules and coarse prismatic structure. Dips 5° to south. Carbonates constitute only 6% and the matrix does not break down in acid: only quartz peaks show on the X-ray diffractogram, indicating a siliceous cement, soluble in sodium hydroxide. (Contact wavy, abrupt, interdigitated and conformable.)

Unit Ei. 1·4 m. Cemented, stratified (banded), white, cryptocrystalline calcite with rare calcite pebbles (as unit B). Inclination 1° or more to south. The non-carbonate residue (34%) is a moderately sorted, silty-sand clay (similar in composition to unit C). Apart from calcite and quartz, the X-ray diffractogram shows illite and potash feldspars. This stratum is interbedded with detrital lenses (Eii), up to 30 cm thick, of (a) semi-cemented, white, poorly-sorted silty-clay sand with calcareous concretions and prismatic structure (Sample 1926A, Figure 2), and (b) semi-cemented, very pale brown, silty-clay sand, moderately sorted, with only 1–10% carbonates and coarse angular blocky structure (Sample 1936B). The upper half of Ei has been weathered, with evidence of repeated resolution and precipitation of calcite along bedding planes; soil pipes of unconsolidated, moderately-sorted, silty sand (Sample 1654B) (subunit Eiv) penetrate to the base. (Contact wavy, gradual and conformable.)

Unit Eiii. 0·45 m. Well-cemented, finely-laminated to banded, white and pink, cryptocrystalline calcite with characteristic caliche/*croûte zonaire* structure and now considerably weathered. The non-carbonate residue (25%) is a moderately sorted, silty-clay sand with only 26% clays and colloids. Decalcified soil materials of similar or coarser texture follow the many vertical solution pipes as well as the bedding planes. (Contact wavy, abrupt and erosional.)

Unit F. 0·15–0·8 m. Unconsolidated, weakly stratified, red-brown, moderately sorted, silty sand, only 5% soluble in acid. This slightly humic topsoil has contributed the major part of the soil pipes penetrating unit E, but the texture is far too coarse to be derived from decalcification of unit Eiii.

Detailed interpretation of the Doornlaagte strata

The basic sediment types represented at Doornlaagte are three: (1) massive calcite deposits with clayey residues (Units A, C and Ei), (2) massive calcite deposits with interbedded crude detritus (Unit B) or with sandy residues (Unit Eiii), and (3) sandy lenses with some cementation by colloidal silica and carbonates (Units D and Eii) (see Figure 2). The individual units will now be discussed in turn, partly with reference to samples of modern *vloer* deposits collected from a functional pan on the Brakdam farm, 7 km east of Rooipan (Figures 1 and 2).

Unit A is a typical freshwater limestone, a primary depositional feature of lacustrine origin that has neither genetic nor lithologic similarity with the various pedogenetic or groundwater-calcretes defined by Netterberg (1969*a*, *b*). The sand component, which is the least sorted of the Doornlaagte sequence and comprises less than 5% by total sediment weight, is minimal compared with the samples of modern marls of Brakdam. This suggests a subaqueous environment subject to little or no aeolian deposition and sufficiently extensive that lateral fluvial detritus was practically unrepresented. Significant, too, is the absence of facies variation. Altogether it is probable that this lake was permanent.

Unit B marks a change in micro-environment despite the basic medium of a freshwater limestone. Fluvial (or wave) erosion attacked consolidated materials from Unit A and reworked them by rolling as well as sliding, judging by pebble shape. Positive skewing (Figure 2) as well as the presence of crude igneous detritus speaks for a more regional mode of denudation and periodic high-competence transport of mixed-grade, coarse detritus. The sandy pockets have grade maxima near 120 μm and, judging by the good sorting, may represent aeolian components. Finally, the local mass death of hygrophile snails of identical size/age speaks for periodic desiccation. All of these indicators modify the picture of a lacustrine depositional environment: in addition to long intervals with standing water, there was repeated desiccation with some aeolian sedimentation, interrupted by episodes of torrential surface runoff that swept an influx of crude subaerial sediment across the gently-sloping margins of the *vloer*. Bed B is therefore interpreted as a mixed lacustrine-colluvial sediment.

The nature of the archeological residues in their geological context is discussed in the concluding section.

Units C, D and E mark a third major environmental pattern in the Doornlaagte sequence. Coarse colluvial components are very rare. Instead, there are abrupt facies changes due to lenticular interbedding of sands within a broad spectrum of freshwater limestones. The clay-residue cryptocrystalline calcites are precipitates laid down in standing waters, while we interpret the bulk of the sands as reworked aeolian deposits. These are well-sorted and medium-grade, but subangular except for the very top of the column, suggesting derivation from local igneous outcrops by repeated reworking through different agencies. In terms of basic composition these sands are similar to the aeolian/semi-aeolian Clovelly soils of Van Rooyen (1971, p. 51 ff., Chap. 5): such profiles are developed south of the present study area in sands of local origin deflated from stream beds and certain pans. At Doornlaagte we posit accretion of shallow aeolian drifts, on a dry pan surface or along a pan margin, with possible subsequent reworking by wave agitation or running water—all prior to secondary impregnation with clays, colloidal silica, and carbonates. The replacement of clay by sand as the insoluble residue of the top third of unit E implies that aeolian components became increasingly important during the terminal stages of sedimentation. In fact these final sediments recall those currently forming in the modern pan at Brakdam (Figures 1 and 2). However, the Unit Eiii sands are well rounded and thus resemble the allochthonous aeolian sands of "redistributed Kalahari" type (see Van Rooyen, 1971, Chap. 5 for comprehensive discussion), although the characteristic ferric skins are absent (reduced?) and there is conspicuous micro-pitting ("frosting," see discussion by Butzer & Gladfelter, 1968). We interpret the last by superficial corrosion of quartz in an alkaline environment.

After the Doornlaagte site had finally drained, pedogenetic processes did indeed modify the upper parts of Unit E into a laminated calcareous crust, caliche, or calcrete of type envisaged by Netterberg (1969*b*), specifically to a variant of his "hardpan calcretes". However, we differ fundamentally in considering the underlying strata A-C and Ei as primary freshwater limestones and not as secondarily calcified detritus. Pedogenetic change has only modified the topmost sedimentary column.

The subsequent geomorphic record of Doornlaagte is sparsely rendered by an interval of calcrete solution and soil pipe formation. A mixture of surface wash, in good part of aeolian derivation, consequently found its way into solution pipes, cavities, fissures, and bedding planes of the uppermost "calcrete". The overall porosity of unit E is largely a result of this period of leaching and of a pedogenesis antithetical to calcrete formation.

Rooidam

The nature of the site

The late Acheulian ("Fauresmith") site of Rooidam lies 25 km west of Kimberley, a little south of the new Kimberley-Douglas highway near the farmhouse of C. J. Cohn (see Figure 1) (28° 47′ S and 24° 31′ E).

Artifacts were first recognized among the rubble of a well shaft in 1963 and a 1-month excavation was carried out by G. J. Fock in mid-1964 (Fock, 1968). A stepped trench was dug to a depth of 5 m, with a minimum size of 1·8 × 5·4 m. Since scattered artifacts were found at all levels below 1·2 m, apparently without forming concentrated "floors", and since the sediments were thoroughly indurated, difficult to differentiate and, above all, mainly horizontal, the excavation was carried out in horizontal spits of up to 15 cm thick (Fock, 1968, 1972). Artifacts are found to a depth of 5·4 m in the well-shaft adjacent to the trench, but no typological trends or changes are evident through this total sediment thickness of 4·3 m. Fock (1968) provides a preliminary tabulation for each level: excluding 11,866 waste flakes, chips and flaked chunks, there are 6925 tools, flakes, and cores. The total number of hand-axes (127) and cleavers (33) is small, and the former are primarily of ovate or lanceolate type. Lydianite (a contact metamorphic rock, derived from shale) and, in five instances, diabase form the raw material: the exact source of the diabase is unknown, but lydianite outcrops about 1 km to the west (Fock, 1972). Although most of the artifacts are in mint condition, a fair proportion are somewhat worn or corroded. The dolerite cobbles found scattered in those levels with greater artifact concentration are too strongly weathered to allow recognition of battering marks or flaking scars. A representative selection of artifacts has also been illustrated by Clark (1970, Figure 22), who agrees with Fock regarding the appellation "Fauresmith."

The Rooidam site represents part of a complex sedimentary sequence which mantles most of an elongated *vloer* that measures 6 × 13 km and terminates in the Karee Pan (Figure 1). This *vloer* now drains a basin approximately 8 × 18 km. Although the Karee *vloer* is mainly underlain by Dwyka Shale, Karoo Dolerite outcrops around most of the peripheral watershed. No Ventersdorp Diabase is exposed in the area (DuToit, 1907–08). The site itself lies near the northern perimeter of the Karee *vloer*, at an elevation of 1150 m. The general area is covered by the 1:50,000 topographic sheets sheets 2824-CD and DC (Koedoesbergdrif and Spytfontein), compiled in 1968–69, with geological coverage by DuToit's (1907–08) 1:238,000 map.

The sedimentary sequence at Rooidam

The total thickness of sediment overlying dolerite bedrock is 9·5 m at the immediate site, and Fock (1968, Figure 2) gives a generalized section as follows, from bottom to top:

(1) 1·2 m dolerite rock with matrix of red sand; some artifacts;

(2) 2·9 m sterile red sand, capped by ferruginous horizon;

(3) 3·0 m calcareous sand and silt with lenticles of red sand, including the major artifact concentrations, scattered freshwater shells (*Bulinus tropicus* and *Planorbis natalensis*), and a single fragment of ostrich shell;

(4) 1·2 m soft, surface limestone with occasional artifacts;

(5) 1·0 m hard, surface limestone, sterile;

(6) 0·2 m surface wash.

A more detailed section was made by the writer on the north side of the excavation (Figure 3) during brief visits in 1969 (with R. G. Klein) and 1970 (with G. J. Fock and D. M. Helgren). A total of 17 sediment samples were collected and subsequently analyzed at the University of Chicago. These are presented by the composite profile of Figure 4, which includes the excavation face and a section of the well shaft: the basal well section was not sampled in place, but derived materials were examined from the adjacent tailings. The stratigraphic complex can be described as follows on the basis of the macroscopic and laboratory data.

Unit O. 0·6 m. Rubble of decomposing dolerite cobbles and blocks, with limited sandy matrix similar to overlying horizon and possibly derived from it. Partly waterworn detritus, partly bed-rock regolith. Includes occasional rolled or badly corroded artifacts, such as a few large flakes, a possible core and a chopper. (Contact irregular and abrupt.)

Unit A. 3·8 m. Unconsolidated, stratified, red-yellow, non-calcareous, silty sand with moderate sorting and weak structure. The sands are quartz, have ferric skins, and are subrounded to rounded in shape, while the coarser sands consist largely of fine igneous

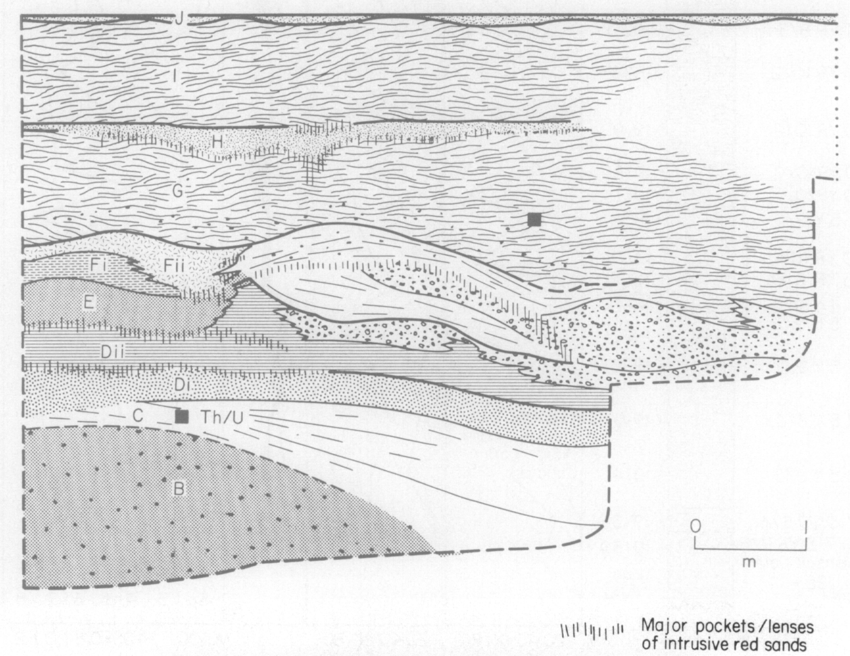

Figure 3. Generalized section of Rooidam (north wall).

rubble. Scattered dolerite cobbles occur in the bottom 0·6 m or so (Ai), where there may be incipient calcareous concretions. The major body of sediment (Aii) is homogeneous and has better-sorted sands (Sample 1913 A), while the topmost 0·2 m (Aiii) is more compact and has rather more silt (Sample 1913 B). The entire unit is archaeologically sterile. (Contact wavy and abrupt.)

Unit B. 1·5 m. Compact, weakly stratified but prismatic-structured, white, silty-clay sand to clayey-silt sand, poorly to moderately sorted. The non-carbonate residue includes 16–27·5% clays and colloidal silica. The sands from the middle of this unit are best sorted and positively skewed, while those at the top are very fine and negatively skewed. Sands over 300 µm consist primarily of igneous minerals. Traces of pyrolusite staining and some fine, faint mottles of very pale brown colour. Colloidal silica attains almost 20% in the lower parts, while the top third is secondarily calcified (up to 45% $CaCO_3$).

Major archaeological concentrations at this level comprise Fock's 12 ft 6 in to 18 ft 6 in levels, including 89% of his tools, flakes and cores, and 96% of his *débitage*. They are found in crudely-stratified horizons, associated with rotting dolerite cobbles. All of the freshwater snails recovered during the excavation came from this bed (Fock, 1972). (Contact smooth and clear.)

Unit C. 0·2–0·5 m. Compact to cemented, stratified, white marl with several laminated calcareous crusts that thicken and feather out to the east; spongy honeycomb of secondary calcification widespread. The non-calcareous residue (23%) is a moderately

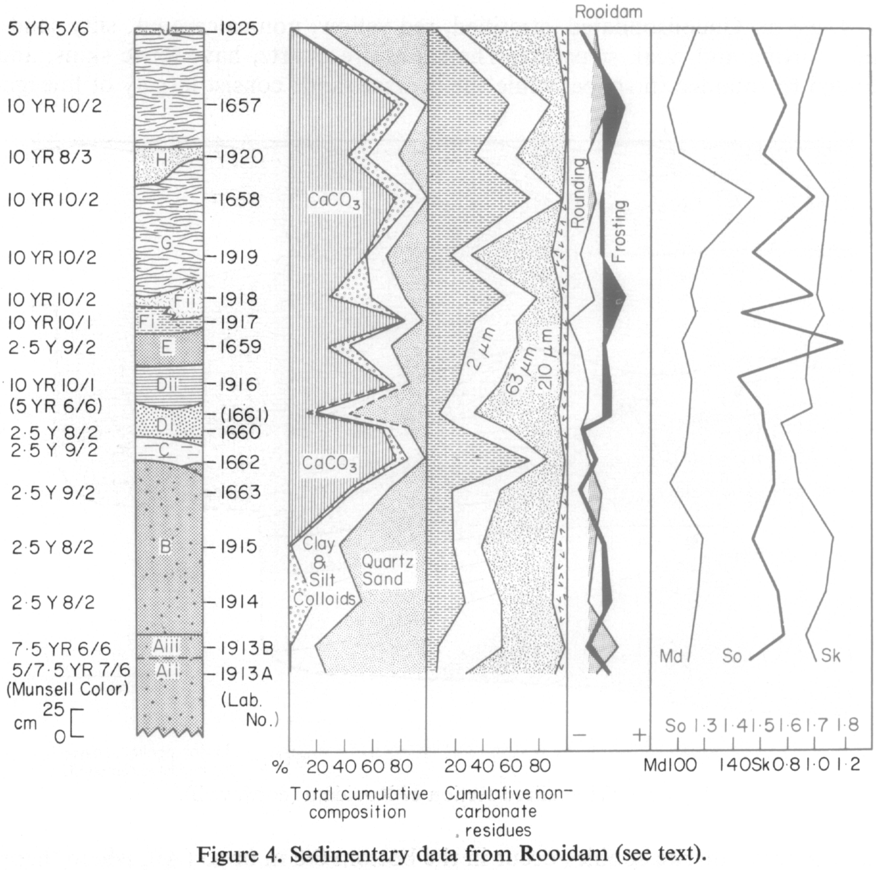

Figure 4. Sedimentary data from Rooidam (see text).

sorted sandy-silt clay with 73% clays and colloids. Apart from calcite and quartz, the X-ray diffractogram shows illite and montmorillonite in equal proportions, with a trace of kaolinite and potash feldspar. A few artifacts. (Contact wavy and abrupt.)

Unit Di. 0·3 m. Compact weakly stratified but prismatic-structured, white marl, with a non-calcareous residue (32%) of moderately sorted clayey-silt sand (23% clays and colloids). Corroded bedding planes and veins are now widely filled with intrusive, red-yellow, moderately-sorted, decalcified silty sand (Sample No. 1661). Modest artifact concentration (essentially Fock's 10 ft 9 in–11 ft 6 in level) with decomposing dolerite chunks. (Contact wavy and abrupt.)

Unit Dii. 0·3 m. Cemented, stratified to laminated, white marl. Non-calcareous residue (29%) of moderately-sorted, clayey-silty sand with 22% clays and colloids. Veins of intrusive, pink (5 YR) soil wash at top. (Contact wavy and abrupt.)

Unit E. 0·3–0·7 m. Compact to cemented, weakly stratified, white, poorly-sorted clayey-sand silt (28% colloids and clays in non-carbonate residue), secondarily calcified, primarily in the form of vertical root drip. Laterally interdigitated with banded to laminated marl (as Unit D), including several new lenses of marl and calcified loam toward east. Loamy lenses contain chaotically-bedded artifacts (essentially Fock's 9 ft 6 in–10 ft 6 in unit). Upper contacts marked by extensive veins of intrusive, red-yellow (5 YR), soil wash. (Contact wavy and clear.)

Unit F. 0·2–0·4 m. Partially cemented, banded to laminated, white marl (Fi), interdigitated with prismatically-structured marly clay (Fii). The marl has a moderately-sorted non-carbonate residue (18%) of silty-clay sand with 34% clays and colloids. The marly clay has a moderately-sorted, non-carbonate residue (71%) of sandy-silt clay with 56% colloids and clays. Moderate concentrations of artifacts in marly clay (essentially Fock's 9 ft–10 ft unit). (Contact wavy and abrupt.)

Unit G. 0·9 m. Cemented, massive-bedded, white marl and cryptocrystalline calcite with a non-carbonate residue (24–45%) of clayey-silt sand to silty clay, including very coarse sand grains of igneous debris in the basal part, and ranging from 15 to 72% clays and colloids. Apart from calcite and quartz, the X-ray diffractogram shows illite and montmorillonite (in approximate ratio of 2:1), as well as a trace of potash feldspars and kaolinite. Numerous local pockets and veins of pink (5 YR) soil wash, particularly along uppermost contact. (Contact wavy and abrupt.)

Unit H. 0·1–0·3 m. Compact, well-stratified, very pale brown, calcified (41% carbonate), silty-clay sand (33% clays and colloids in non-carbonate residue). Occasional fine dolerite pebbles. Last artifacts. (Contact wavy and abrupt.)

Unit I. 1·0 m. Cemented, finely-laminated to banded, white marl and cryptocrystalline calcite with characteristic caliche structure. The non-carbonate residue (23%) is a moderately-sorted, sandy-silt clay with 58% clays and colloids. Abundant yellow-red (5 YR) soil wash in fissures and bedding planes, particularly in strongly-weathered, topmost 30 cm. (Contact straight and abrupt.)

Unit J. 0–0·3 m. Unconsolidated, stratified, yellow-red, weakly-structured, non-calcareous, moderately-sorted, silty sand. Nearby sections include derived materials from Unit I, interbedded with Middle Stone Age artifacts.

Detailed interpretation of the Rooidam strata

The basic sediment types at Rooidam both differ from and resemble those of Doornlaagte: (i) Low-porosity, cryptocrystalline calcites are poorly developed except within the pedogenetically altered, i.e. calcreted uppermost strata (G and I). Instead there are porous, non-crystalline marls with clayey residues (Units C, G and I). (ii) Crude detritus is absent except for the basal stone line (Unit 0), and even here not associated with marls or calcities. Marls with sandy residues (Units Di, Dii, and Fi) may compare with sandy calcites at Doornlaagte but resemble secondary calcretes. (iii) Sandy strata with some cementing carbonates or colloidal silica are represented by Units B, E, H and, less typically, by the cemented clayey bed Fii. (iv) The non-calcareous, reddish sandy beds of Unit A compare closely with the surface wash at both sites but find no parallel in the Doornlaagte sequence proper. (v) Sands are less well sorted at Rooidam than at Doornlaagte, despite the similarity of grade-size and symmetry. (vi) The Rooidam sediments are comparably altered by pedogenetic calcretion of the upper units and by intrusive reddish, sandy soils that follow lines of decalcification. In part these differences reflect on a different intensity of diagenesis at Rooidam. More importantly, they reflect on a different history of sedimentation in a comparable macro-environment. The individual strata will now be discussed, followed by a more general evaluation of both sites.

Unit O suggests colluvial rubble resting on weathered igneous bedrock, and clearly predates local *vloer* sedimentation.

Unit A corresponds closely to the Hutton soils of Van Rooyen (1971, p. 45 ff.) which are formed in aeolian or aeolian-derived materials (Van Rooyen, 1971, p. 81 ff.). We consider the basic sediment (Aii) to be a colluvial product of aeolian origin, already weathered as a surface soil prior to reworking. The topmost bed (Aiii) is somewhat less porous due to an appreciable silt content that, on the basis of poorer sand sorting, may reflect on derivation from more mixed source materials. The ferric oxides adhering to the sand grains of unit A have not been reduced and mobilized, suggesting that anaerobic reducing conditions have never applied, despite the lacustrine nature of several of the overlying strata.

Unit B is more problematical. Eliminating the colloidal silica which is secondary, the clay fraction remains near 15% throughout the sediment column, with silt increasing at the top to replace sands coarser than 200 μm. Aeolian components are most prominent in the middle of the unit, and in most respects this basic silty sand, with its subrounded quartz grains, corresponds to the aeolian or aeolian-derived Clovelly soils of Van Rooyen (1971, p. 51 ff.): the difference lies in the moderately-strong prismatic structure, which in part reflects on secondary silicification and calcification. However, the characteristic presence of freshwater snails closely ties Unit B to a freshwater depositional setting. The genera *Bulinus* and *Planorbis* are quietwater snails that thrive in stagnant, muddy waters but have a low tolerance for sodium and nitrate concentrations (Harris, 1965): neither snail is compatible with a hyper-alkaline lake. We therefore suggest an aeolian ridge or lunette bordering immediately on a shallow, periodic lake fed by rainfall and surface run off. Such lunettes are not uncommon today along the eastern or southern margins of pans in the northern Cape Province, where deflation is restricted to the dry season or whenever the floor of the depression is dry.

The post-depositional induration of Unit B involved both colloidal silica and calcium carbonate. The concentration of the former at the base and the latter at the top suggests two possible hypotheses: (a) that impregnation with mobilized silica preceded calcification, or (b) that silicification and calcification were simultaneous, except that the silica was more mobile than the carbonates. The close association of colloidal silica and carbonates in most strata at both Rooidam and Doornlaagte seems to favor the second explanation.

Unit C was certainly not deflated from the sandy bottom of a seasonal or ephemeral lake. The clay and carbonate speak for aquatic, low-energy sedimentation, while the feathering-out of the strata above the sand ridge B indicate submergence in a deeper lacustrine medium. The multiple calcrete laminae strongly suggest (but do not prove) periodic submergence and emergence.

Unit Di is almost identical to the top of Unit B, except that sediment accretion was horizontal, and probably slow, on a flat surface. This could imply another semi-aeolian, lakeshore setting or, in analogy with modern lime-mud flats at Brakdam (Figure 2), pan conditions with a lower lake level. The carbonates may or may not be secondary. The subsequent bed Dii is finer and exhibits laminar bedding. Similar but lenticular alternations of prismatic sandy facies and laminated calcified facies continue through Units E and F. In the meanwhile clay/sand ratios—if colloidal silica is subtracted from the clay fraction—remain constant through Di, Dii, E and Fii, indicating an initial clayey-silt sand texture with poor sorting. Clays are twice as high in some lenses such as Fi, but even here the original texture was a clayey-silt sand. Sporadic occupance is recorded only from the prismatic lenses.

Several basic deductions can be made from this arrangement of facies in Units Di to Fii: (a) rapid alterations of depositional media transporting and depositing similar materials; (b) sedimentation on an undulating surface dipping approximately 2° to the east; (c) periodic, lenticular and probably penecontemporaneous carbonate precipitation, in the main part subaquatic. The most basic overall interpretation must be a meso-environment with alternating re-working of sediments by wind and water during periodic emergence and submergence. The closest sedimentary analog is provided by the modern pan sampled at Brakdam (Figures 1 and 2). Here there is a seasonal alternation between standing waters and cracking, lime-mud. Subangular, dolerite-derived, subangular quartz sand is washed in by colluvial agencies during the rainy season, with some lenticular concentration into grey, clayey marl (Sample 1921A) and light brown-grey, sandy marl (Sample 1921B) along the *vloer* margins. During the dry season thin films of carbonate evaporate on the surface of low, undulating convexities, whereas the concavities retain moisture somewhat longer or stay within the capillary zone of the water-table. The subangular sands and the bedding of Units Di to Fii suggest a similar *vloer*-margin setting, and the high degree of chemical pitting ("frosting") of the sands would be most compatable with precisely such a hyper-alkaline environment.

Unit G probably marks a progressive change from the sandy margins of a periodically-flooded *vloer* to a more central location, with deeper, more perennial waters and next to no influx of lateral detritus. The limited sand component is rounded and presumably in good part aeolian. After a brief return to a mud-flats condition with Unit H, lacustrine sedimentation resumed and continued throughout the time span covered by Unit I.

The subsequent evolution of the Rooidam area was much the same as that of Doornlaagte: (a) pedogenetic modification of the uppermost 1·5 m or so to a hardpan calcrete, and (b) leaching and washing of reddish, sandy soils into solution cavities as much as 3·5 m below the surface.

General Evaluation

Problems of pan development

An overall assessment of Doornlaagte and Rooidam in terms of palaeo-environmental and stratigraphic implications is only possible in the context of pan evolution in the northern Cape Province. However, the origin of pans is a matter of ongoing controversy that has generated a voluminous literature since the turn of the century, yet providing few simple answers. Furthermore, the writers' field work was not directed towards this geomorphological problem, nor were the site-specific studies adequate to resolve matters of regional landscape evolution. The following remarks are consequently offered only to show that these archaeological sites must be understood in a broader environmental context.

Pans are most frequent in the Kalahari and, elsewhere, in the broad belt of the Interior Plateau underlain by Karroo rocks of the Dwyka and Ecca Series (see Van Eeden, 1955). In detail, the majority of but not all pans on erosional topography occur in relation to lithological discontinuities reflected in differential weathering and erosion (see Wellington, 1943, 1945). Structural predispositions and ongoing, gentle deformations additionally influence pan location (Brink, 1969). Many pans are currently dammed, by alluvial or aeolian sands in some instances, by resistant igneous thresholds in others. Another common but not ubiquitous trait of pans on Karroo rocks is a linear arrangement in broad valley-like systems that dip and wind their way towards the major rivers (see Geyser, 1950). A further characteristic is that the pans on erosional Dwyka and Ecca topography are clearly favored by the low relief, exceptionally gentle regional dips, and the limited degree of dissection of even the major drainage lines across the planation surfaces of the Interior Plateau (see DuToit, 1907, 1933; King, 1968, p. 271 ff. and Figure 119; Wellington, 1955, p. 32 ff., 1958). Despite their distribution over a broad—arid to subhumid—climatic range from 100 to 800 mm annual precipitation, almost all authors are agreed that deflation plays a prominent role in pan development or remodelling today. Finally, a good case can be made for the role of large herds of gregarious herbivores removing considerable quantities of sediment from wallows over protracted periods of time: in this way, given an initial basin with standing water, animal excavation would actively complement deflation (Flint & Bond, 1968; also Alison, 1899).

Examination of the topographic maps shows that both the Rooipan and Karee *vloers* lie within shallow, poorly-defined valley systems draining southward to the Riet River (Figure 1). Both of these palaeo-valleys are discernible on the air photos, although difficult to recognize at ground level due to low gradients and relief. The longitudinal profiles of the termini both project onto erosional surfaces at some 75 m above the present Riet floodplain.

Evolution of these now-defunct valleys must have been a complex process. The net gradient of the Palaeo-Rooipan River amounts to 75 m over the 20 km stretch to the upper margins of the Riet valley, although the relief of surficial pan deposits within the Rooipan *vloer* is at least 50 m. Even within this *vloer*, drainage is not integrated and the shallow peripheral drainage lacks defined channels prior to entering the string of unconnected pans that increase in size and depth, culminating in Rooipan. It would appear that the original valley was formed selectively along weaker Dwyka shales amid Ventersdorp diabase and Karroo dolerites. At some early stage deflation, in combination with continued chemical weathering and fluvial erosion, created a series of pans along various valley systems draining towards the Riet River. At other times, ponding in the increasingly complex valley systems created widespread lacustrine conditions. D. M. Helgren (in preparation) identifies at least 4 such cycles of pan erosion and lacustrine deposition in the Kimberley region, the youngest of which is exemplified by the Upper Pleistocene deposits of the Alexandersfontein Pan (Figure 1) (Butzer *et al.*, 1973); Rooidam is associated with the deposits of the penultimate lacustrine hemicycle, and Doornlaagte with those of the antepenultimate (Helgren, 1973). These deductions are compatible with other lines of evidence.

Palaeo-pedogenetic considerations

Although palaeosols have here been of less interest than sedimentary processes, several pedogenetic phenomena require brief discussion: calcretes, silcretes and ferric palaeosols.

A variety of calcareous sediments and soils have been considered. It remains to assess the palaeo-environmental implications of pedogenetic calcretion. Goudie (1972, 1973) has reviewed the extensive literature on calcretes, and Mountain (1967) has attempted a provisional map of fossil and developing calcretes in southern Africa, showing a strong regionalization in arid and dry-semiarid regions, supporting the opinion of Bond (1963) and Netterberg (1969*a*, *b*) that major calcretes are found in areas that now enjoy less than 550 mm annual precipitation. All this is in agreement with the basic premise that pedogenetic carbonate enrichment is only possible when soil-moisture evaporation roughly matches or exceeds infiltration water. This poorly-understood balance is of course locally or regionally modified by such factors as permeability and porosity, as well as primary abundance of carbonates. Above all, the time-depth of most calcretes, which therefore reflect on past rather than contemporary environmental parameters, renders climatic "precisions" difficult and precarious. The only possible conclusion with regard to calcrete formation at Doornlaagte and Rooidam is that this process is, or theoretically should be, compatible with a climate much like the present. Whether, in fact, it might have reflected on slightly moister or slightly drier conditions is a moot point.

Silcretes were first identified in southern Africa by Siegfried Passarge at the turn of the century. Nonetheless, the sporadic references in the literature (e.g. Cooke, 1941, p. 25; DuToit, 1954, p. 477 ff.) have hardly contributed to an understanding of this process of cementation by colloidal silica that leads, in extreme cases, to the formation of chalcedonic chert or quartzite. Fossil silcretes are best developed in presently arid sectors of southern Africa (Mountain, 1967). One of the few serious attempts to interpret such phenomena is that of Conrad (1969, p. 333 ff.), who concludes that fossil Saharan silcretes formed along former desert margins in close relationship to a standing water-table. This would appear to agree with the observation of Van Eeden (1955), that siliceous duricrusts up to 60 cm thick are found capping the sand bars that rise just above water-level in pan lakes of the southern Kalahari: these bars may be partly-submerged aeolian lunettes. It is therefore possible that the colloidal silica component at Doornlaagte and Rooidam has no inherent palaeoclimatic interest, reflecting instead on geo-hydrologic conditions—after sedimentation and prior to pedogenetic calcretion.

Pedogenetic decalcification with the formation of some variety of fersiallitic soil is indicated at both Doornlaagte and Rooidam. Admittedly a substantial part of the soil-pipe fillings, represented by the pink to red-yellow silty sand at both sites, is derived from surface soils that are primarily of distant, aeolian origin. But the honeycomb of such soil products, penetrating to $-3{\cdot}5$ m depth at Rooidam, necessarily includes the residual products of *in situ* decalcification. Without raising the question of whether or not the reddish Hutton soils of the Kimberley region are, after all, palaeosols, the nature of at least one extended phase of post-calcrete pedogenesis at both Doornlaagte and Rooidam corresponded closely to that associated with modern fersiallitic soils of the southwestern Transvaal, an area where precipitation now ranges from 425–725 mm. A circumstantial argument can therefore be made that the soil-pipes and part of their fillings represent the lower B-horizons of fersiallitic soils, developed under environmental conditions a little moister than those of the present.

Palaeo-environmental interpretation of the sedimentary sequences

In the light of the previous discussions, the sedimentary profiles at Doornlaagte and Rooidam can be evaluated in a general context. With the exception of the freshwater snails mentioned, there is unfortunately no palaeo-biological evidence. DuToit (1907) mentions diatoms from pan deposits in the Northern Cape, and Kent & Rogers (1947) describe them from various parts of South Africa. No diatoms were found in the samples processed for the present study. E. M. van Zinderen Bakker kindly examined calcite samples from Doornlaagte (Units A, B and Ei) and Rooidam (Unit G), finding microscopic vegetable remains, but no pollen. Consequently the present assessment must essentially be confined to geomorphological and sedimentological criteria.

The history of the former pans at Doornlaagte and Rooidam is summarized in Tables 1 and 2, with reference to the detailed discussion and to Figures 2 and 4. The interpretations vary in their degree of probability and may well require modification and amplification if and when more detailed geochemical analyses become available.

(a) It is at once apparent that the overall trend of relative water-levels at Doornlaagte and Rooidam is reversed. The former sequence begins under mesic conditions, becomes highly periodic and then shifts to a xeric environmental pattern. The latter depositional suite begins on a xeric level, becomes seasonally-wet and terminates on a mesic note as aeolian conditions begin. Clearly the two sequences are not coeval. Since diagenesis is considerably more advanced in the Doornlaagte sediments, and since other factors are more or less identical at both sites, Doornlaagte must be somewhat older than Rooidam.

(b) The initiation and the termination of pan conditions at either site are difficult to interpret environmentally. Both seem to have formed and ultimately desiccated in response to processes normal to the cyclic development of valley *vloers* postulated above. This does not preclude the role of climatic oscillations in alternating erosion of and sedimentation in successive pans. So, for example, accentuated rainfall periodicity with dry-season deflation would favor pan creation, while more mesic conditions favor net sedimentation and gradual filling. Ultimately a return to the initial conditions created a new pan at a lower elevation, so draining the intact, older and higher *vloer*. Although both deepening and infilling can be seen in different pans of the Kimberley District today, pans are very small in terms of *vloer* size and areas of active sedimentation are quite restricted. In other words, the proportional area covered by pans (with net erosion) versus *vloers* (with net deposition) has fluctuated through time.

Table 1. The Doornlaagte sequence

(Bed) Thickness	Description	Facies (process) interpretation	Pan conditions and water level
	(Top)		
—	Solution, leaching, soil-pipe formation	Subhumid pedogenesis	Subaerial
—	Calcretion (hard-pan variant)	Semiarid pedogenesis	Subaerial after desiccation
(Eiii) 0·5 m	Cryptocrystalline calcite with sandy residue	Pan-reworked aeolian sands of distant origin	Low (seasonal, standing waters) with increasing aeolian activity
(Ei) 1·4 m	Cryptocrystalline calcite with clayey residue, interbedded with lenses of prismatic sandy sediment with abundant colloidal silica	Primary, freshwater limestone with lenticular reworked aeolian material	Low (shallow with periodic desiccation)
(D) 0·3 m	Prismatic sands	Reworked lens of aeolian sand	Low (seasonal, standing waters)
(C) 0·5 m	Laminated, cryptocrystalline calcite with clayey residue and abundant colloidal silica. Some artifactual materials and hygrophile snails	Primary, freshwater limestone (lacustrine)	High (moderately deep but fluctuating)
(B) 0·6 m	Coarse pebbles and cobbles, and abundant artifactual material in matrix of laminated, cryptocrystalline calcite with clayey residue and proliferations of hygrophile snails	Mixed lacustrine-colluvial	Low (shallow with periodic desiccation and sheet-floods)
(A) 2·4 m	Stratified, cryptocrystalline calcite with silty to clayey residue	Primary, freshwater limestone (lacustrine)	High (deep, ? permanent)
	(Base)		

(c) The oscillating water levels indicated within the sedimentary profile at each site cannot be attributed to a closed-system scheme of geomorphic evolution. Instead water levels must have reflected aperiodic trends of a hydrologic balance ultimately controlled by regional climate. So, for example, lower glacial-age temperatures, such as those evident in the southeastern and northern Cape (see Butzer & Helgren, 1972; Butzer, 1973*b*, *c*), would have reduced evaporation at all seasons and helped maintain deeper pan-lakes. Similarly, increased rainfall and/or reduced periodicity favors a more complete mat of grassy vegetation, retarding runoff and reducing the seasonal amplitude of

Table 2. The Rooidam sequence

(Bed) Thickness	Description	Facies (process) interpretation	Pan conditions and water level
	(Top)		
—	Solution, leaching, soil-pipe formation	Subhumid pedogenesis	Subaerial
—	Calcretion (hard-pan variant)	Semiarid pedogenesis	Subaerial after desiccation
(I) 1·0 m	Laminated marl and calcite with clayey residue	Primary, freshwater marl with aeolian influx of distant origin	High (deep but periodic, with moderate aeolian activity)
(H) 0·2 m	Stratifield, calcified	*Vloer* mud-flats	Low (shallow, periodic)
(G) 0·9 m	Massive marl and calcite with residue grading upwards from sandy to clayey texture. Abundant colloidal silica in upper part	Sandy *vloer*-margin deposits, then primary, freshwater marl with some, distant aeolian components	Rising (increasingly deep and permanent, with accelerating aeolian activity)
(F) 0·4 m	Laminated marl (with sandy residue) interdigitated with prismatic marly clay Some artifacts. Clay rich in colloidal silica	Lenticular, intercalated *vloer*-margin deposits (beds F–Di)	Low (shallow, periodic) (beds F–Di)
(E) 0·5 m	Prismatic, calcified silts interdigited with laminated marls. Some artifacts		
(Dii) 0·3 m	Laminated marl with sandy residue		
(Di) 0·3 m	Prismatic marl with sandy residue. Some artifacts		
(C) 0·4 m	Inclined-bedded marl with calcrete laminae and clayey residue	Primary, freshwater marl (lacustrine)	High (deep but periodic)
(B) 1·5 m	Prismatic sands with abundant archaeological materials and freshwater snails. Top calcified, base rich in colloidal silica	Aeolian shore ridge	Low (shallow, periodic)
(A) 3·8 m	Stratified, reddish sands with some basal cobbles	Colluvial, reworked aeolian sands	Subaerial, with considerable aeolian activity
(O) 0·6 m	Stone line of cobbles and blocks, with rolled artifacts	Colluvial	Subaerial, with effective sheet-floods
	(Base)		

changes in lake volume. By way of hypothesis, a 5°C lowering of temperature *or* a 50% increase in rainfall would not change the *BSkw* climatic classification for Kimberley: however, in the first instance vegetation would probably shift to *sweet veld* grassland, but remain *thornveld* in the second case (see Clark, 1967, pls. 9–10 and p. 8 ff.; also Cooke, 1964). Palynology and alluvial geomorphology (van Zinderen Bakker, 1957;

van Zinderen Bakker & Butzer, 1973) argue that late Pleistocene climatic anomalies have remained within such hypothetical confines, while optimal moisture balances appear to have involved a comparable degree of change.

(d) Pedogenetic calcretion at both sites followed desiccation and increased aeolian activity. This indicates that, in the two specific instances studied, macro-climate was at least as dry as it is today, possibly more so. A 50% decrease in rainfall would change Kimberley's climate to desert (*BWkw*) and the local vegetation to *Karroo shrub* (see Clark, 1967, pl. 8). Changes of this magnitude have indeed occurred in the Free State during parts of the late Pleistocene (van Zinderen Bakker & Butzer, 1973). It is doubtful whether active pan deflation at the lowest points of the *vloer*, combined with the advance of "Kalahari"-type sands from the Vaal River, requires desert conditions. Nonetheless, a more open vegetation of Karroo shrub would certainly accelerate both processes.

(e) Decalcification and fersiallitic pedogenesis suggest conditions much like those of the *sweet veld* in the southwestern Transvaal. Possibly these subaerial processes were laterally equivalent to and coeval with the lacustrine situations.

(f) The crude colluvial components of Doornlaagte Unit B fall completely outside the range of contemporary processes in the Kimberley District. In fact, analogues must be sought in the crude local detritus locally interbedded in valley-margin exposures of the mid-Pleistocene Vaal gravels (see Butzer *et al.*, 1973). Since overland flow is inadequate for such surface denudation today, protracted, high-intensity rains must be postulated and a fluctuating lake or pan level argues for marked rainfall periodicity. A good model appears to be given by a *thornveld* with perhaps 50% more rainfall during the rainy season.

In conclusion, the geomorphic evolution and sedimentary history of Doornlaagte and Rooidam provide informative and provocative records of mid-Pleistocene environmental change in the Kimberley region. The qualitative aspects of these fluctuations are unassailable, but we caution the reader that the speculations as to rainfall anomalies and vegetation type are only offered as working-hypotheses and not as concluding syntheses.

External stratigraphic relationships

The previous discussion has assumed that both Doornlaagte and Rooidam are, broadly speaking, of mid-Pleistocene age. In default of paleontological materials, several methods of external correlation are suggested.

(a) *Radiometric dating.* The late Pleistocene alluvial history of the river valleys (see below) as well as the coeval evolution of the Alexandersfontein Pan (Butzer *et al.*, 1973) show that the sedimentary carbonates at both sites would be well beyond the dating range of radiocarbon. However, the denser marls and calcites probably lie within the scope of thorium-uranium or protactinium dating. Particularly promising in this regard would be assays on beds A and Ei at Doornlaagte, and on C and G at Rooidam. A preliminary Th/U date of 115,000 ± 10,000 BP has been obtained for Rooidam unit C by Szabö (1973), and the unusually high initial level of uranium suggests that this date is chemically reliable.

(b) *Geomorphologic dating.* Upland calcretes and freshwater limestones are demonstrably older than a variety of late Pleistocene, non-functional alluvial deposits at many points along the Modder, Riet and Vaal Rivers (Butzer, 1971*a*, and unpublished; Butzer *et al.*, 1973). Consequently we have strong reservations concerning the over-simplified calcrete stratigraphic scheme of Netterberg (1969*a*), whereby the Doornlaagte calcrete is assigned to the "First Intermediate", the Rooidam calcrete to the "Second

Intermediate" period, i.e. roughly early and late Upper Pleistocene (!) respectively. Instead we agree with Harmse (1971) that there have been repeated and protracted periods of calcrete formation in the general area during mid-to-late Pleistocene times, and that the initial creation of the *vloers* probably goes back to the early Pleistocene.

(c) Indirectly relevant to matters of stratigraphy is that the youngest Acheulian (including "Fauresmith") of southern Africa is not now known to overlap with the Middle Stone Age, which dates back to considerably "greater than 50,000 BP" on the basis of a growing body of ^{14}C dates (Beaumont & Vogel, 1972). In fact the stratigraphically earliest Middle Stone Age on the Cape coast must be correlated with the last, high interglacial sea-level (Butzer, 1973*c*). Thus the Acheulian/Middle Stone Age transition appears to lie *prior to* 75,000 BP, near the Middle/Upper Pleistocene transition, an age compatible with our 115,000 BP date for the Rooidam Acheulian ("Fauresmith").

Correlations of the Doornlaagte and Rooidam Acheulian with other Acheulian collections or assemblages are another matter. Mason (1973) indicates that the Doornlaagte artifacts generally resemble the middle to upper Acheulian of the Vaal "Current Gravels" (see Partridge & Brink, 1967) or "Younger Gravels" at Windsorton. Employing length/width ratios of the hand-axes, Fock (1968) concludes that the Rooidam assemblage is more "evolved" than that of any of the Windsorton collections. However, Fock (1968) also notes that the same ratio varies randomly from 55 to 86 in 16 different levels at Rooidam, a range of variation that would encompass all 3 sites at Riverview Estates near Windsorton. We feel that these length/width ratios are not reliable as presently used. (i) Among the ratios for each hand/axe form-type there is more, unsystematic variation within each of the Vaal River collections (see Cole, 1961, Table 2) than there is between the means of all Acheulian collections so far studied from southern Africa. (ii) The numbers of hand-axes measured within each form-type from the Vaal collections and from Rooidam are far too small (between 1 and 38) to carry any statistical significance. (iii) In view of the small and rather variable hand-axe suites measured it is probable that primary variations in raw material type, shape, and size will have significantly modified the ultimate morphology of finished hand-axes. Consequently, in the writer's opinion there are at present no sound typological arguments for stratigraphic differentiation of the Acheulian in the Northern Cape.

In conclusion, the Doornlaagte and Rooidam sequences date from the Middle Pleistocene. The geomorphic events recorded at each site do not overlap, while the regional geomorphologic development indicate that (a) Rooidam belongs to a younger lacustrine hemicycle than Doornlaagte (Helgren, 1973) and that (b) both sites are older than Upper Pleistocene lacustrine episodes.

Site Context of the Archaeological Residues

It remains to discuss the archaeological materials of Doornlaagte and Rooidam in their immediate geological context.

The Acheulian of Doornlaagte, Unit B, must be understood in terms of a mixed, colluvial-lacustrine depositional environment.

(a) Presumably the site was occupied at times when water was present in close proximity, and not a time when the pan was quite dry or when torrential runoff inundated this location. Some artifacts are waterworn and others not, precluding wholesale derivation. Together with the lack of dip-related orientation (see Mason, 1967, Figure 3), this argues for selective disturbance by running water. It seems to us that the artifacts exposed at any one time were dispersed on an irregular surface, only rarely disturbed in its totality by high-competence flow. Most runoff episodes were probably diffuse, with multiple rills channelling water among higher, pebbly ground on which artifacts generally remained undisturbed.

(b) Consequently we would agree that the site is, to a certain degree, "intact" but generally in semi-primary, as opposed to primary context. Most of the Unit B artifacts are concentrated at the top of the bed, and Mason's floor plan of artifact distribution represents a single horizon at the surface of Unit B (Mason, 1973). Thus there appears to have been one episode of major occupance during a long period of repeated but ephemeral use of the general site area.

(c) The "manuports" and unmodified rocks pose a problem, much as they do at all Acheulian sites that include colluvial or alluvial components (see Butzer, 1973*a*). The great bulk of igneous pebbles and cobbles was washed into the area by sheetfloods or concentrated runoff, so that there was no need to carry in exotic rock. The extent to which available, on-the-spot rock was disturbed or utilized by man remains difficult to ascertain. Fortunately the exacting nature of the excavation should allow a realistic reassessment of the unmodified igneous rock in this perspective.

The final stages of Acheulian occupation at Doornlaagte are recorded by the artifacts and "disturbed" cobbles in Unit C. Ephemeral, pan-side settlements or butchery sites seem to be implied. Ultimate abandonment of this traditional territory may have reflected increasing desiccation, whereby mobility would have been impeded at significant distances from predictable water.

The Acheulian at Rooidam also appears to have been a temporary lakeside settlement, occupied during the high-water season. The major occupation is closely linked with an aeolian shore ridge (Unit B), and a comparable geo-archeological context is present in the late Pleistocene (*c*. 30,000 BP) site-complex of Lake Mungo, N.S.W., Australia (Bowler *et al*., 1970). In terms of evaluation of Rooidam Unit B:

(a) It is probable that each subhorizontal level of concentration represents a temporary occupation surface.

(b) The presence of some 6100 artifacts and flakes with 11,300 pieces of *débitage* in a small section of sediment (1·8 × 3·5 m in plan, 0–1·4 m thick) can only be construed as an exceptionally rich artifactual concentration, involving on-the-spot flaking. Yet the source of raw material was 1 km distant, so that this was not only a lydianite workshop but also an occupation site. The dolerite cobbles must all be considered as manuports since throughout beds A–F they occur only in association with artifacts and lack any predictable relationship to textural spectra. However, the function of these cobbles remains obscure due to the advanced state of spheroidal weathering.

(c) Whether or not the artifactual material of Rooidam Unit B is in primary association can only be determined by a meticulous excavation beyond the original possibilities of Fock's exploratory trench through 3·5 m of cemented overburden. Both the limited degree of wear—whether by use, water or wind—as well as the phenomenal concentration of artifacts suggest a semi-primary if not a primary context.

The limited numbers of artifacts in several higher levels at Rooidam (Units D–F and H) are generally, although not exclusively associated with subaerial *vloer*-margin deposits. The sparse distribution and the increased ratio of waterworn (or corroded?) specimens suggests a semi-primary context at best. Nonetheless, their very presence indicates repeated, sporadic lakeside or pan-floor visitations for millenia after the initial, key period of occupance. The paucity or absence of artifacts in the sub-aquatic marls seems reasonable in that seasonal visits by Acheulian man would have been delimited by the contemporaneous shoreline.

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